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NAVIGATING UNCERTAINTY: HOW ECONOMIC POLICY UNCERTAINTY SHAPES THE IMPACT OF GROWTH AND RENEWABLE ENERGY ON CO2 EMISSIONS

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Abstract

This study examines the relationship between economic growth, renewable energy consumption, and CO2 emissions, while investigating the moderating role of Economic Policy Uncertainty (EPU) across 30 provinces in China from 2009 to 2020. Using the PCSE and FGLS estimators, the research found a positive and significant impact of both renewable energy and economic growth on CO2 emissions, indicating that despite the shift towards greener energy sources, rapid economic activity and the expansion renewable infrastructure may still contribute to environmental degradation. Notably, the results highlight a negative and significant moderating effect of EPU on the relationship between both renewable energy and economic growth with CO2 emissions. This suggests that heightened policy uncertainty weakens the direct impact of economic and energy variables on environmental outcomes, likely by disrupting investment flow delaying clean energy projects, or increasing risk aversion in green transitions. The study offers nuanced insights into the dynamic environmental effects of macroeconomic and policy factors in a rapidly developing economy, underscores the importance of policy stability in achieving effective environmental governance.

1. Introduction

Over the past few decades, China has achieved substantial economic advancement, becoming the world's second-largest economy and a key player in international trade and investment. However, this rapid growth has also made China the leading global emitter of carbon dioxide (CO2), rising significant environmental concerns both within the country and worldwide (Vitenu-Sackey & Acheampong, 2022). As china seeks to balance economic progress with environmental sustainability, examining the link between economic growth, energy consumption, and CO2 emissions has become increasingly important for policymakers, researchers, and society (Shahriyar Mukhtarov, 2023). Economic expansion often correlates with increased industrial activity and energy use, leading to higher carbon emissions. Fossil fuel-based energy sources, which have largely powered China's growth, remain a major contributor to ecological degradation (Jiang et al., 2019). Therefore, it is now more important than ever to combat climate change and cut carbon dioxide emissions. Consequently, the global community is now more focused on switching to renewable energy sources in order to lessen the negative impacts of using conventional energy sources (Zahra Dehghan Shabani, 2024; Jeon, 2022). Balancing carbon emissions with economic development has emerged as a crucial priority. Achieving ecological sustainability alongside economic growth requires a clear understanding of the current state of decoupling between economic progress and CO2 emissions in Chinese cities, as well as the factors contributing to this separation. The organization for economic co-operation and development originally introduced the concept of decoupling to assess how economic growth impacts the environment (Zhang & Sharifi, 2024, Adil et al., 2024). Economic policy uncertainty reduces the usage of items high in energy and pollutants, according to their consumption effect. As a consequence, ecological damage will be reduced. However, uncertainty in economic policy discourages advancement in research and investing in renewable energy, which increases environmental problems (Jiang et al., 2019; Wang et al., 2020).

In the context of this study, Ecological Modernization Theory provides a theoretical basis for the expectation that renewable energy consumption can mitigate the negative environmental effect traditionally associated with economic growth. As provinces experience economic expansion, the integration of renewable energy technologies can reduce dependence on fossil fuels, thus lowering CO2 emissions (Alkhalili et al., 2023). According to EMT, this technological shift should occur more rapidly as regions become wealthier and more industrialized. EMT suggests that while economic growth combined with renewable energy consumption can reduce environmental harm, stable and predictable policy environments are critical for this modernization process to succeed.

Neoclassical Growth Theory explains how economic growth inherently increases the demand for energy consumption. As economic grow, industries expand, transportation increases, and consumer demand rises, all leading to greater energy needs. Traditionally, much of this energy demand has been met through fossil fuels, which are directly associated with higher CO2 emissions (Gori et al., 2021).

The primary aim of this research is to analyze how economic growth and renewable energy consumption influence CO2 emissions, while considering the moderating role of economic policy uncertainty (EPU). Specifically, the study seeks to: (a) explore the link between economic growth and CO2 emission, (b) evaluate the contribution of renewable energy in reducing emissions, (c) assess how EPU moderates these relationships, and (d) offer empirical insights at the provincial level. The study suggests that governments should maintain stable and transparent economic and environmental policies to attract investment in renewable energy. Given the diversity in economic structures, energy capabilities, and policy sensitivities across provinces, tailored regional strategies are essential rather than uniform national solutions. During periods of high EPU, it is vital to implement firm and consistent environmental regulations to avoid a regression into fossil fuel dependency. Moreover, sustained support for the renewable energy sector is crucial to curbing emissions during economic growth phases, even amidst policy uncertainty. (a) This research provides an innovative perspective by incorporating EOU as a moderating factor in the relationship between economic growth, renewable energy use, and CO2 emissions across 30 provinces in China. (b) It further contributes by using provincial-level data to draw comparisons between the eastern, central, and western regions of the country.

2. Literature Review

Understanding the determinants of carbon dioxide (CO2) emissions is essential for achieving sustainable development and addressing climate change. Among the key variables influencing emissions are economic growth and renewable energy consumption. More recently, economic policy uncertainty (EPU) has emerged as a significant factor that can alter the direction and strength of these relationships. This literature review synthesizes past studies on these variables and highlights gaps in the research that support the inclusion of EPU as a moderator.

2.1 Economic Growth and CO2 Emissions

An investigation conducted by Mikayilov et al. (2018) analyzed the relationship between economic growth and CO2 emissions using the data from Azerbaijan spanning 1992 to 2023. Employing a cointegration framework, their results indicated a positive and statistically significant long-term association between economic growth and CO2 emissions. They also found that any short-term deviations from this equilibrium could be corrected in less than a year. In Zhang and Sharifi (2024) authors explained this relationship in Chinese capital cities from 2011 to 2021 using the Tapio decoupling model and the LMDI decomposition method. Their findings revealed that the CO2 emissions continue to rise slowly, and the COVID-19 phenomenon generated enormous fluctuations in 2019-2021. There are notable variations among cities some achieve consistent weak decentralization, while others have unstable decentralization. Additionally, there are several benefits to economically prosperous cities. Investigation conducted by Raza and Tang (2024) demonstrated that the overall factors show significant impacts on carbon emission. The increases in CO2 emissions are due to the largest contributions of population and energy, at 15% to 16%, respectively. In Pakistan, Import/export and financial status are the least significant contributors to merchandise and income per capita, at 12% to 13%, respectively. According to Kasperowicz (2015) focused on 18 EU countries between 1995 and 2012 using an Error Correction Model. The study revealed a negative long-run relationship between GDP and CO2 emissions, attributed to advancements in low-carbon technologies that support sustained output with lover emissions. However, in the short term, a positive relationship was observed, suggesting that increased production through modern technology initially drives up energy use and emission. An investigation conducted by Onofrei et al. (2022) also explored this nexus in EU countries over the period 2000-2017 and found a significant long-term link between economic growth and CO2 emissions, using the DOLS estimation method to confirm their findings.

2.2 Renewable Energy consumption and CO2 Emissions

According to Waheed et al. (2018) analyzed how renewable energy consumption, forest, and agriculture activity affect CO2 emissions in Pakistan using annual data from 1990 to 2014. Their findings showed that both renewable energy and forest expansion have a statistically significant negative impact on CO2 emissions over the long term, indicating that greater forest areas and increased use of clean energy help reduce environmental degradation. Conversely, agricultural activities were found to contribute positively and significantly to CO2 emissions in the long run (Raihan et al., 2022). Investigation conducted by Zahra Dehghan Shabani (2024) investigated the moderating role of human capital in the relationship among renewable energy and CO2 emissions with the using of 67 countries included in the dynamic panel data model from 1999-2019. Their findings showed that renewable energy has an adverse effect on CO2 emissions, and this effect become more pronounced when human capital is high. In fact, once the human capital index surpassed a certain threshold, the mitigating effect of renewable energy on CO2 emissions became 4.75 times stronger in advanced economies and five times stronger in developing countries (Gnangoin et al., 2022). In Huang et al. (2021) authors explained the link between renewable energy and CO2 emissions in major energy-consumption countries from 2000 to 2015 using the generalized method of moments (GMM). They concluded that renewable energy use has a statistically significant and negative effect on emissions. In another investigation, Mendonça et al. (2020) examined CO2 emissions in the 50 largest economies were affected by GDP, population,

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and the production of renewable energy from 1990 to 2015. Their findings showed that the four types of barriers financial, technological, political, and social preventing the development of renewable energy in several nations. According to Shahriyar Mukhtarov (2023) revealed that factors such as total productivity, exports, and renewable energy usage have a adversely impact on CO2 emissions, whereas import and income levels tend to elevate them.

2.3 The interaction of EPU in Economic growth, Renewable energy and CO2 Emissions

An investigation conducted by Adedoyin et al. (2020) explained the relationship between tourist arrivals, energy consumption, economic policy uncertainty (EPU), and ecological footprint in the top ten tourism revenue-generating countries from 1995 to 2015 using FMOLS and DOLS estimation techniques. Their findings indicated that EPU positively moderates economic the relationship between economic growth and energy consumption. According to Adedoyin et al. (2021) examined how renewable and non-renewable energy consumption affects CO2 emissions in 32 Sub-Saharan African between 1996 and 2014, they used generalized method of moments method. According to the one-step system-GMM results showed that the production of non-renewable energy and real gross domestic production both raise CO2 emissions. The moderation impact of EPU on the impact of both energy productions yields a decrease in the region's emissions level. According to Li and Haneklaus (2021) revealed compelling evidence for the long and short-term presence of an inverted U-shaped connection among CO2 emissions and economic growth. CO2 emissions are currently rising as a rising as an effect of China's renewable energy sector's explosive growth. Research conducted by Vitenu-Sackey and Acheampong (2022) revealed that growth in economies has a significant and positive impact on CO2 emissions, yet only at the ideal rate of development, after which emission levels decline. EPU effects on CO2 emissions are varied; only within excessive-polluting nations do high EPU levels significantly affect CO2 emissions; in low-polluting nations, they do not. In Farooq et al. (2023) the authors explained the impact of EPU, renewable energy consumption, on environmental sustainability. Using China's data from 1995-2021 and the ARDL model for analysis. Their finding showed the effect of energy consumption on CO2 emissions has negative and significant, but the effects of Urbanization, foreign direct investments, and economic policy uncertainty on CO2 emissions are strong.

H1: Positive and significant impact of economic growth on CO2 emissions

H2: Positive and significant impact of renewable energy on CO2 emissions

H3: significant moderation impact of EPU relationship between economic growth, renewable energy and CO2 emissions.

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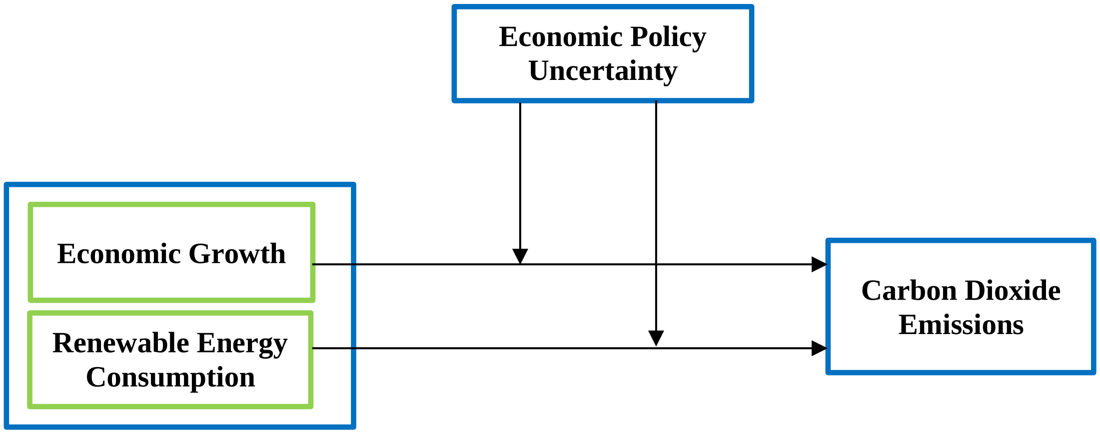

Figure 1. Conceptual framework of the current study.

3. Research Methodology

3.1 Data Sampling and Variable Measurement

This study investigates how economic growth and renewable energy consumption influence CO2 emissions, considering the moderating effect of economic policy uncertainty (EPU). It utilizes a balanced panel dataset covering 30 provinces across mainland China from 2009 to 2020. Data for the analysis were sourced from China's statistical yearbook. The dependent variable in this research is CO2 emissions, while the key independent variables are economic growth and renewable energy consumption, with EPU serving as a moderating factor. Additionally, control variables such as foreign capital inflows and industrial value-added are incorporated. Detailed descriptions of all variables are provided in Table 1.

3.2 Econometric Model

To empirically examine the influence of economic growth and renewable energy consumption on CO2 emissions, along with moderating role of Economic policy uncertainty, this study adopts a panel data regression framework. The current study's empirical approach entails analyzing the correlation between the dependent variable, namely, CO2 emissions (carbon dioxide emissions), along with other independent variables. Independents variables include real GDP per capita (EG) and the proportion of renewable energy in total energy consumption (REC). Additional control variables are incorporated to enhance the robustness of the findings and to provide a more comprehensive understanding of how economic growth and energy use affect CO2 emissions.

Table 1. Variables Measurements

Variables	**Symbols**	**Descriptions**	**Authors**
CO2 Emissions	CO2	Annual CO2 emissions per province	Li and Haneklaus (2021)

Economic Growth	EG	Real GDP per capita	Zahra Dehghan Shabani (2024)
Renewable Energy Consumption	REC	The proportion of renewable energy in total energy consumption	Mendonça et al. (2020)
Economic Policy Uncertainty	EPU	Provincial EPU Index	Khalid et al. (2025), Adil et al. (2025)
Foreign Fund Flows	FFF	The influx of finance from international sources into the provincial industry	Hussain et al. (2025)
Added Values of Industry	AVI	Contribution of the high-tech industry through production, innovation, and other value-added activities.	Amna (2020)
Research & Developments	RND	Provincial industrial investment in innovation and technological improvement	Hussain et al. (2025)

$$CO2_{i,t} = \propto + \beta_1(EG_{i,t}) + \beta_2(EPU_{i,t}) + \beta_3(\textstyle\sum_{CONTROLS_{i,t}}) + \varepsilon_t \quad \textbf{(1)}$$

$$CO2_{i,t} = \propto + \beta_1(EG_{i,t}) + \beta_2(EPU_{i,t}) + \beta_3(EG \times EPU_{i,t}) + \beta_4(\textstyle\sum_{CONTROLS_{i,t}}) + \varepsilon_t \quad \textbf{(2)}$$

$$CO2_{i,t} = \propto + \beta_1(REC_{i,t}) + \beta_2(EPU_{i,t}) + \beta_3(\textstyle\sum_{CONTROLS_{i,t}}) + \varepsilon_t \quad \textbf{(3)}$$

$$CO2_{i,t} = \propto + \beta_1(REC_{i,t}) + \beta_2(EPU_{i,t}) + \beta_3(REC \times EPU_{i,t}) + \beta_4(\textstyle\sum_{CONTROLS_{i,t}}) + \varepsilon_t \quad \textbf{(4)}$$

Equation 1 captures the relationship between economic growth and CO2 emissions, incorporating several control variables, with error term ε_t accounting for unexplained variability in the model. Equation 2 builds upon the first by introducing economic policy uncertainty (EPU) as a moderating factor in the link between economic growth and CO2 emissions. Equation 3 focuses on the effect of renewable energy consumption on CO2 emissions, while Equation examines the moderating influence of EPU on this relationship. For the primary analysis, the study utilizes the panel-corrected standard errors (PCSE) method, and the feasible generalized least squares (FGLS) technique is applied for robustness checks. The analysis is based on a balanced panel dataset from 30 Chinese provinces, covering the years 2009 to 2020, totaling 360 observations.

Table 2. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max

CO2	360	16.089	.096	15.859	16.208
EG	360	9.725	0.891	6.986	11.615
REC	360	2.62	0.11	2.442	2.784
EPU	360	5.978	0.669	4.735	6.674
FFF	360	13.706	2.509	6.028	17.897
AVI	360	8.878	0.932	6.095	10.698
RND	360	12.316	1.855	5.889	16.446

Table 3. Findings of Pairwise Correlations

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
(1) CO2	1.000						
(2) EG	0.335	1.000					
(3) REC	0.882	0.336	1.000				
(4) EPU	0.882	0.321	0.901	1.000			
(5) FFF	0.068	0.758	0.049	0.055	1.000		
(6) AVI	0.235	0.967	0.212	0.220	0.720	1.000	

(7) RND	0.297	0.868	0.315	0.299	0.809	0.809	1.000

4. Results Interpretation

Table 2 shows the descriptive statistics of this study. All data must fall between the upper and lower ranges, which represent the maximum and minimum values of the data, respectively. The standard deviation is the data's departure from the mean value. A higher standard deviation exacerbates the problem of outliers, which makes it undesirable for analysis. The total observations of our analysis are 360. The standard deviation is the data's deviation from the mean value. The mean value of the dependent variable CO2 emission is 16.089, maximum and minimum values are 15.859 and 16.208. Independent variables EG and REC mean value are 9.725 or 2.62, while the minimum values of EG and REC are 6.986 or 2.442, and the maximum value of EG and REC is 11.615 or 2.784. The moderating variable EPU mean value is 5.978, and the minimum and maximum value of the EPU is 4.735 or 6.674 (Jiang et al., 2019; Kailash Chandra Pradhan et al., 2024). According to the representative, 30 Chinese provinces use renewable energy to meet their energy needs.

Table 3 represents the findings of pairwise correlations between dependent, independent variables, and other variables. The purpose of this analysis is to ascertain the strength and direction of a linear relationship between two distinct variables. Our results indicate that the correlation values decrease within acceptable bounds, suggesting a decreased probability of multicollinearity among the variables. The dependent variable CO2 positively correlates with independent variables EG (0.335), and REC (0.882). The correlation between CO2 and moderating variable EPU is positive (Shahriyar Mukhtarov, 2023; Zhang & Sharifi, 2024).

Table 4. Findings of Variance Inflation Factor

Variable	VIF	1/VIF
EG	6.62	0.151
REC	5.585	0.179
RND	5.581	0.179
EPU	5.32	0.188
FFF	3.605	0.277
AVI	3.482	0.287
Mean VIF	5.032	.

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Table 4 shows the variance inflation factor analysis of this study. This statistical technique is also used to diagnose multicollinearity in data. Value of VIF is greater than 10 so that the multicollinearity are exists between the explanatory variables. The VIF values for all explanatory variables are below the critical value of 10, with most ranging between 3.482 and 6.62. This suggests that multicollinearity is not a concern, and the regression coefficients are unlikely to be distorted by intercorrelated predictors (Hussain et al., 2025; Cem Işık et al., 2024).
The unit roots and Pesaran analysis are presented in Table 5. These tests include Levin-Lin-Chu, Im-Pesaran-Shin, and Pesaran CD. These tests were used to check the data stationarity in this study. The results of our analysis show that all variables are significant and stationary in the first difference, therefore we say that stationarity exists in our data.

Table 5. Findings of Unit Roots and Pesaran CD Tests

Variable	Levin–Lin–Chu	Im–Pesaran–Shin	Pesaran CD
CO2	-8.2383***	-8.0372***	67.348***
EG	-1.3273**	-3.3231***	81.894***
REC	-3.7312***	-3.8281***	72.853***
EPU	-3.2810***	-2.1728**	69.621***
FFF	-5.4080***	-7.3413***	51.832***
AVI	-1.7846	4.8742	28.126***
RND	-3.4387**	-6.2608***	41.375***

*Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.10$ **

4.1 Primary Analysis

Table 6 reports the results of the main analysis using the Panel-Corrected Standard Errors (PCSE) regression technique. Model 1 shows the impact of independent variable economic growth on CO2 emissions. The findings indicate that economic growth has a positive and statistically significant effect on CO2 emissions, as evidenced by a p-value below 0.05. This suggests that as economic activity increases, CO2 emissions also rises primarily driven by greater energy consumption, industrial production, and consumer demand. Since much of the energy infrastructure still relies on fossil fuels like coal, oil, and natural gas, economic expansion tends to escalate environmental pressures. The increased energy consumption directly leads to higher carbon emissions. Growth in the economy also promotes infrastructure development, urbanization, and transportation, all of which raise emissions considerably. Increases in income also frequently result in more people using air conditioners, electronic devices, and personal cars, which raise emissions and use of energy even more. Several emerging economies expand before strict environmental restrictions are implemented, and the environmental effect is exacerbated by the usage of antiquated and carbon-intensive technology. Therefore, there is a positive and strong correlation between GDP growth and CO2 emissions in the early and intermediate phases of economic development. The scale effect, which is brought on by economic development, occurs when more production and consumption lead to higher resource use and waste creation, including Co2 emissions. Increased volume outweighs the advantages of efficiency gains in the absence of robust environmental regulations (Namahoro et al., 2021; Özden et al., 2021). Model 2 shows that the moderation impact of EPU between economic growth and CO2 emissions is negative and significant. It indicates that economic policy uncertainty refers to the lack of clarity or unpredictability in government policies related to taxes, trade, regulation, or environmental rules. When EPU is high, businesses and consumers are less certain about future economic conditions, which affect investment, production, and energy consumption. Moreover, EPU moderates the relationship between economic growth and CO2 emissions relationship by influencing investment decisions, energy use, and policy implementation. Its effect can dampen or amplify emissions, depending on the context. Therefore, predictable and stable policy environments are crucial to managing emissions while pursuing economic growth (Işık et al., 2024; Benlemlih & Yavaş, 2023).

Table 6. PCSE regression findings with EG as IV

Variable	Model 1		Model 2	
	Coef.	p-value	Coef.	p-value
EG	3.1319 (0.311)	0.000	1.720 (0.0456)	0.000
EPU	0.6633 (0.1199)	0.000	2.6378 (0.0343)	0.000
EG*EPU			-0.2644 (0.0028)	0.000

FFF	-0.0028 (0.0468)	0.951	0.0054 (0.0076)	0.476
AVI	-1.2842 (0.2729)	0.000	-0.0873 (0.0413)	0.035
RND	-0.5659 (0.0694)	0.000	-0.0232 (0.0113)	0.04
Number of obs	360		360	
R-squared	0.9955		0.9999	
Wald chi2	93727.33	0.0000	4736125.43	0.0000

*Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.10$ *; values in parentheses are standard errors.*

Table 7 represents the relationship between renewable energy consumption and CO2 emissions, considering the moderating effect of economic policy uncertainty (EPU). Model 1 specifically examines the direct influence of renewable energy consumption on CO2 emissions. The results indicate a positive and statistically significant relationship, suggesting that an increase in renewable energy usage is associated with a rise in CO2 emissions. This outcome may reflect transitional challenges, such as reliance on hybrid energy systems or inefficiencies in renewable infrastructure during the initial adoption phases. Renewable energy investment often accompanies economic expansion, which increases industrial activity, transport, and infrastructure development. Even though renewables are used more, the overall growth driven-demand for energy may still be met largely by fossil fuels, driving CO2 emissions up. The creation, installation, and maintenance of renewable energy infrastructure, such as wind turbines or solar panels, may generate significant CO2 emissions, particularly if the manufacturing process relies on fossil fuels. Additionally, the development, setup, and upkeep of renewable energy technologies such as wind turbines and solar panels often require processes that emit carbon, including the extraction of rare-earth materials, manufacturing activities, and logistics involved in transportation. Therefore, although renewable are cleaner during operation, the life-cycle emissions may still be considerable if not managed properly. Policymakers and industries must consider upstream and downstream emissions from renewable technologies like production, transport, and disposal. Incentivizing greener supply chains and local manufacturing using clean energy can reduce indirect CO2 emissions (Azer Dilanchiev et al., 2024; Kinyar & Bothongo, 2024). Model 2 reveals that the interaction between economic policy uncertainty (EPU) and renewable energy consumption has a negative and statistically significant effect on CO2 emissions, as indicated by a p-value below 0.05. This suggests that under conditions of elevated policy uncertainty, the positive environmental impact of renewable energy is enhanced. In such contexts, the joint effect of EPU and renewable energy usage contributes to a more substantial reduction in CO2 emissions compared to the effect of renewable energy alone. In times of high EPU, firms face greater risk and unpredictability in investment returns. Fossil fuel projects involve long-term, capital-intensive commitments that become less attractive under uncertainty. Renewable projects particularly solar or wind farms, are modular, less risky, and sometimes subsidized making them more attractive in uncertain times. Although this finding might suggest that economic policy uncertainty can unintentionally lead to environmental benefits by suppressing emissions, it is not a desirable strategy for environmental management. Economic uncertainty can have widespread negative consequences on investment, employment, social welfare.

Table 7. PCSE regression findings with REC as IV

Variable	**Model 1**		**Model 2**	
	Coef.	**p-value**	**Coef.**	**p-value**
REC	7.8990 (0.1319)	0.000	6.3166 (0.0117)	0.000
REC	-0.8724 (0.0457)	0.000	2.3117 (0.0132)	0.000
REC*EPU			-0.9085 (0.0036)	0.000
FFF	0.0505 (0.0147)	0.001	0.0001 (0.0010)	0.916
AVI	0.1661 (0.0356)	0.000	0.0017 (0.0027)	0.516
RND	-0.1275 (0.0228)	0.000	-0.0007 (0.0017)	0.689
Number of obs	360		360	
R-squared	0.9995		1.0000	
Wald chi2	690994.46	0.0000	1.19e+08	0.0000

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*Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.10$ *; values in parentheses are standard errors.*

Under high policy uncertainty, such as unpredictable regulations, volatile incentives, or unclear government support, the expansion and integration of renewable energy may face delays, inefficiencies, or underinvestment. These finding highlights that while renewable energy consumption is effective in mitigating CO2 emissions; its impact is sensitive to the broader policy environment. Policymakers should work to reduce economic policy uncertainty to strengthen the effectiveness of renewable energy policies (Aslan et al., 2024; Gershon et al., 2024).

Table 8 represents the robustness analysis of this study with FGLS regression. Model 1 illustrates the direct effect of economic growth on CO2 emissions, showing a positive and statistically significant relationship, with a p-value below 0.05. This indicates that rising economic output is consistently linked with an increase in CO2 emissions. The observed relationship is likely due to the expansion of industrial operations, greater energy usage, and increased transportation demand that typically accompany economic development all of which contribute to elevated emission levels. Economic growth often leads to more production and consumption, which require greater use of fossil fuels such as coal, oil, and natural gas. These are major sources of CO2 emissions. In many developing or emerging economies, economic expansion is heavily driven by energy-intensive industries and infrastructure development that rely on non-renewable energy sources. Without effective environmental regulations or a shift toward sustainable energy alternatives, this growth leads to a proportionate rise in environmental degradation (Onyeneke et al., 2024; Shahriyar Mukhtarov 2023). Model 2 presents regression results indicating a negative and statistically significant moderating effect of the interaction term EG*EPU on the relationship between economic growth (EG) and CO2 emissions, supported by a p-value well below the 0.05 significance level. This suggests that higher levels of economic policy uncertainty reduce the strength of the positive link between economic growth and CO2 emissions, implying that uncertainty may temper the environmental impact typically associated with economic expansion. In practical terms, the negative sign of the interaction term suggests that during periods of high policy uncertainty, the usual increase in CO2 emissions associated with economic growth is reduced. This can be attributed to firms and investors becoming more cautious during uncertain policy environments, which leads to delays or reductions in energy-intensive investments and production activities. This implies that policy uncertainty play's a meaningful role in shaping the environmental outcomes of economic activities. Policymakers must understand this dynamic when designing strategies that aim to balance economic expansion with environmental sustainability especially in contexts where high uncertainty can indirectly benefit the environment by slowing down carbon-intensive activities. Consequently, less industrial output and energy consumption may result in lower CO2 emissions despite positive economic growth (Huang & Ren, 2024; Gnangoin et al., 2022).

Table 8. FGLS regression findings with EG as IV

Variable	Model 1	Model 2

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	Coef.	p-value	Coef.	p-value
EG	0.0631 (0.0175)	0.000	0.1489 (0.0341)	0.000
EPU	0.1125 (0.0050)	0.000	0.2436 (0.0461)	0.000
EG*EPU	-0.0040 (0.0090)		-0.0138 (0.0048)	0.004
FFF	-0.0040 (0.0021)	0.061	-0.0037 (0.0021)	0.087
AVI	-0.0368 (0.0138)	0.008	-0.0398 (0.0139)	0.004
RND	-0.0022 (0.0036)	0.531	-0.0025 (0.0036)	0.483
Number of obs	360		360	
Wald chi2	947.40	0.0000	959.11	0.0000

*Significance: p < 0.01 ***, p < 0.05 **, p < 0.10 *; values in parentheses are standard errors.*

Table 9. FGLS regression findings with EG as IV

Variable	**Model 3**		**Model 4**	
	Coef.	**p-value**	**Coef.**	**p-value**
REC	0.5498 (0.0473)	0.000	5.0227 0.2438	0.000

EPU	0.0487 (0.0072)	0.000	1.8428 (0.0953)	0.000
REC*EPU			-0.7153 (0.0381)	0.004
FFF	0.0013 (0.0020)	0.526	0.0001 (0.0012)	0.895
AVI	0.0139 (0.0052)	0.008	0.0036 (0.0032)	0.269
RND	-0.0059 (0.0032)	0.067	-0.0013 (0.0020)	0.526
Number of obs	360		360	
Wald chi2	1190.31	0.0000	3125.28	0.0000

*Significance: $p < 0.01$ ***, $p < 0.05$ **, $p < 0.10$ *; values in parentheses are standard errors.*

Table 9 shows the influence of renewable energy consumption on CO2 emissions. Model 1 demonstrates a positive and statistically significant relationship, suggesting that increased use of renewable energy is currently linked with higher emissions. This outcome may stem from several factors, particularly in developing or transitioning economics where renewable energy systems are not yet fully established. These systems often rely on supplementary fossil fuel infrastructure to ensure a stable energy supply, especially given the variability of sources like solar and wind. This transitional reliance may temporarily contribute to higher emissions. The statistical significance of this result, indicated by the p-value, confirms that this relationship is not due to random chance and warrants attention. Thus, while renewable energy remains essential for long-term sustainability, the findings suggest a need for better policy implementation, improved technological efficiency, and a cleaner supply chain to ensure that renewable energy truly leads to a reduction in CO2 emissions over time (Zhou et al., 2024; Mikayilov et al. 2018). Model 2 show the negative and significant moderating impact of the interaction term between renewable energy consumption and economic policy uncertainty on CO2 emissions provides valuable insights into how policy uncertainty influences the environmental effectiveness of renewable energy use. Under high policy uncertainty, firms and investors may adopt a wait-and-see approach, postponing or scaling down production and investment. Consumers may also alter consumption patterns due to economic fears or lack of confidence. In stable policy environment, investments in renewable energy technology and infrastructure are more likely to be sustained, resulting in stronger reductions in emissions. Therefore, policymakers should aim to create stable, transparent, and forward-looking policies that encourage sustainable economic growth rather than rely on uncertainty to limit environmental damage (Farooq et al., 2023; Wang et al., 2020).

5. Conclusion

This study examined the impact of economic growth and renewable energy consumption on CO2 emissions across 30 provinces in China, while also exploring the moderating role of economic policy uncertainty (EPU). The findings contribute to understanding how regional economic and energy dynamics interact with environmental outcomes under varying degrees of policy predictability. The results reveal that increased industrialization and economic activity at the provincial level continue to exert upward pressure on environmental pollution, aligning with the traditional environmental Kuznets curve in its early stages. The interaction in both relationships has negative and significant impacts. The interaction between EG and EPU indicates that uncertainty in policy weakens the positive impact of growth on emissions potentially due to delayed industrial activities or investment hesitations. The interaction between REC and EPU reveals that policy uncertainty diminishes the beneficial environmental effects of renewable energy consumption, possibly through disrupted policy support, investment risk or implementation inefficiencies. Future research could disaggregate renewable energy sources such as solar, wind hydro, and biomass to determine their individual effects on CO2 emissions. This approach would help identify which specific types of renewable energy are more effective in mitigating emissions and how their development is influenced by policy uncertainty. Second, while this study focus on provincial-level data within China, future studies could expand the scope by conducting comparative analyses across different countries or regions, particularly in emerging economies with similar energy and growth patterns. This would provide a broader perspective on how economic and policy environments shape environmental outcomes.

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